Karlsruhe Institute of Technology

Integrating Electric Vehicles into the Electricity System

PD Dr. Patrick Jochem

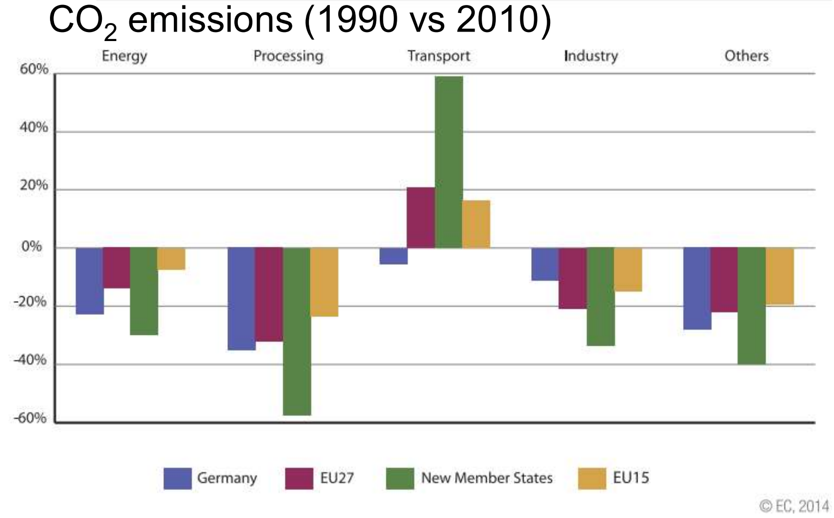
Institute of Industrial Production (IIP), Chair of Energy Economics (Prof. Fichtner)

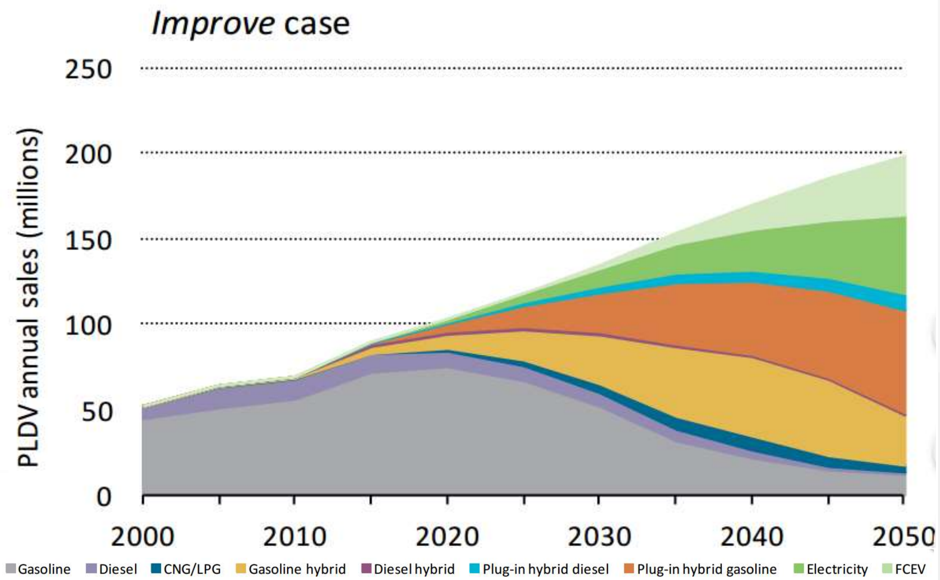
Agenda

- Motivation
- **Electricity demand** by electric vehicles (pattern, volume)
- **Impact on the electricity system** on different grid levels
- **Greenhouse gases** from this additional electricity demand (different countries)
- **Synergies** with electricity from “renweables” and other decentralised energy technologies
- Conclusions

Motivation

- Smog in **mega cities**
- Opposing **trend** from empirical GHG emissions and targets for most countries
- Increasing oil demand and **oil dependency** of many countries and the transport sector in particular
- Fast increasing global **car fleet**
- More and more **stringent standards**
- Challenges in the **electricity system**

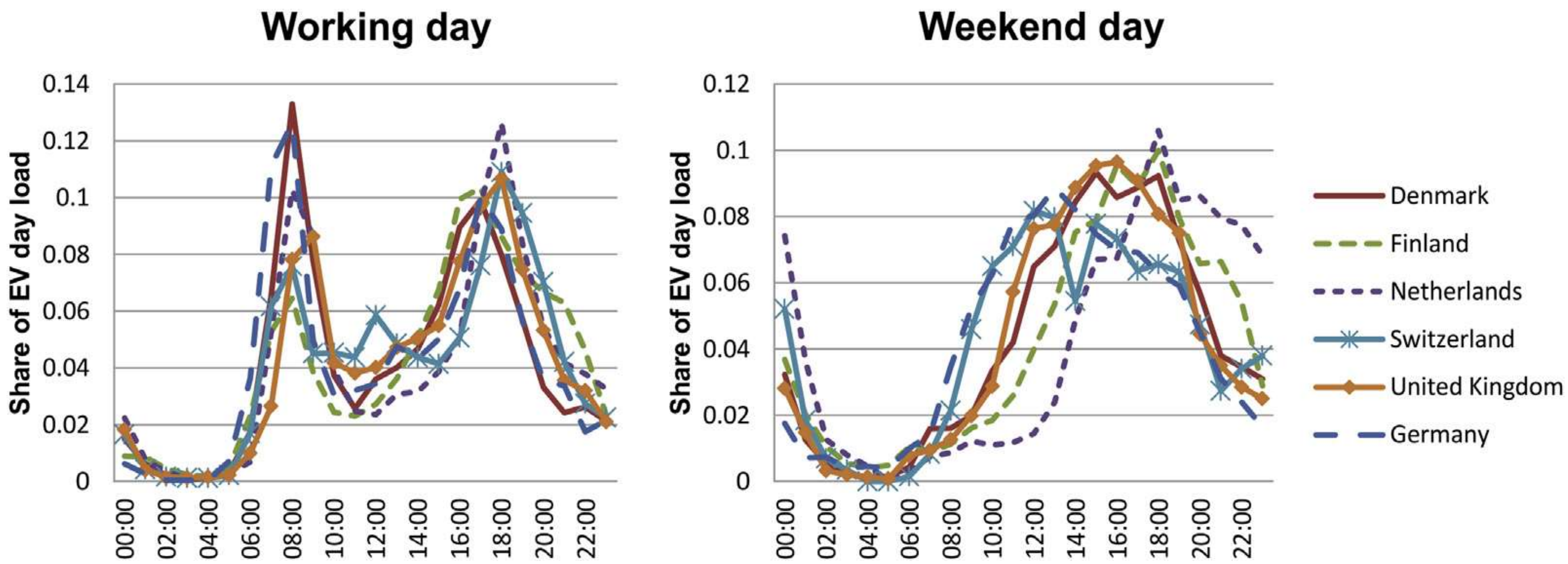




Creutzig, F.; Jochem, P.; Edelenbosch, O.Y.; Mattauch, L.; Vuuren D.P.v.; McCollum, D.; Minx, J. (2015), Transport – a roadblock to climate change mitigation?, Science (Policy Forum) 350 (6263), 911-912

Load patterns by electric vehicles

- Charging load patterns of EV (instantaneous charging)

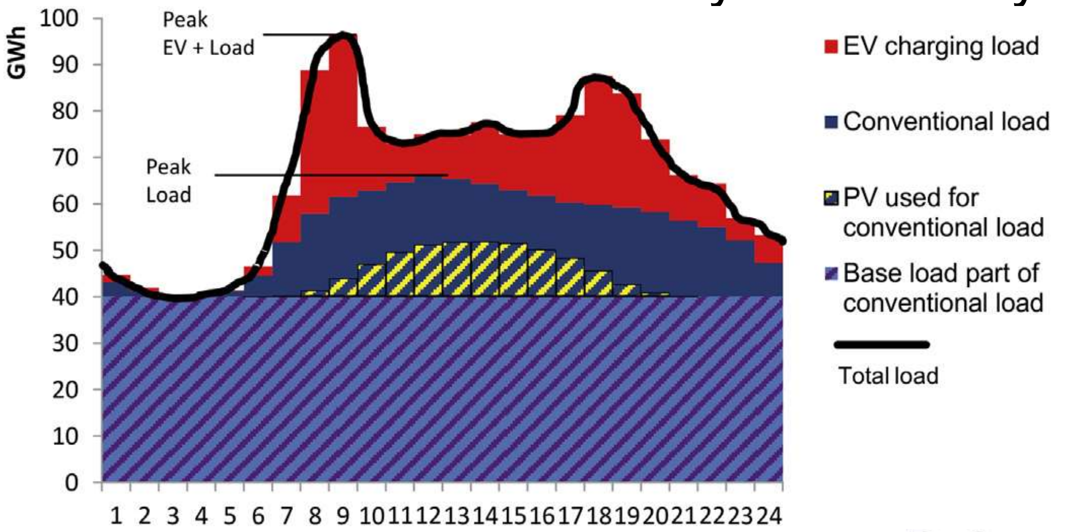


Scenario allows charging at home and at work

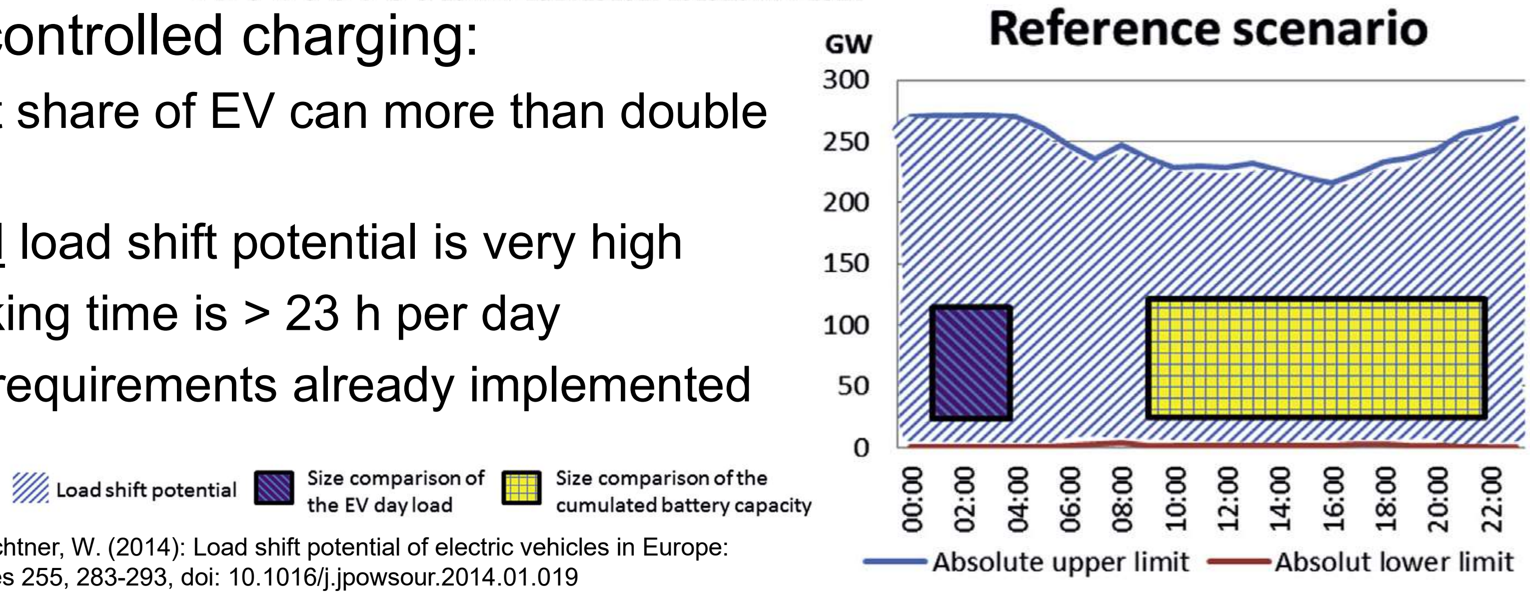
Babrowski, S.; Heinrichs, H.; Jochem, P.; Fichtner, W. (2014): Load shift potential of electric vehicles in Europe: chances and limits, Journal of Power Sources 255, 283-293, doi: 10.1016/j.jpowsour.2014.01.019

Electricity demand by electric vehicles

- 100% market share of EV increases electricity demand by about 20%



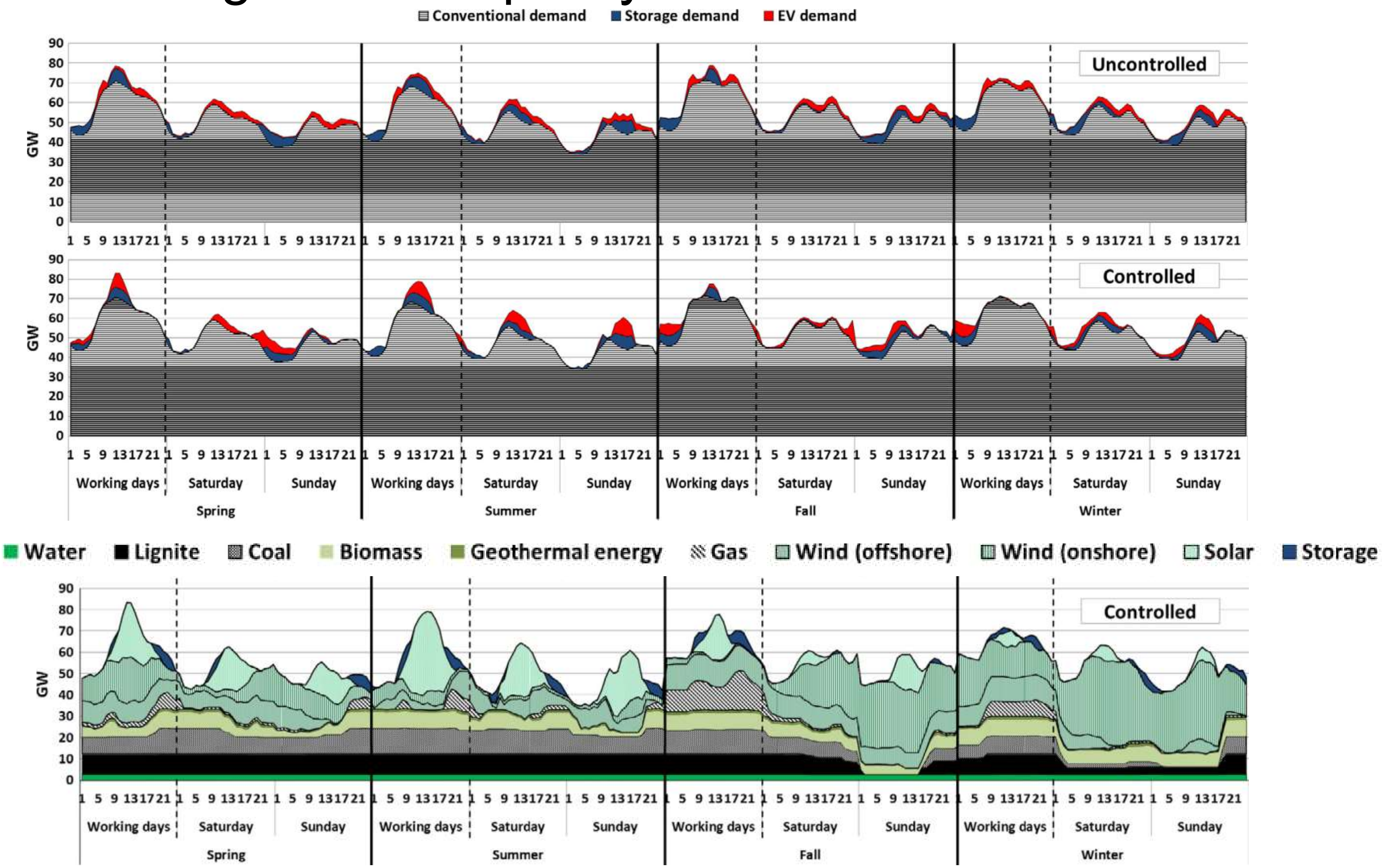
- But we need controlled charging:
  - 100% market share of EV can more than double national load
  - The technical load shift potential is very high
  - Average parking time is > 23 h per day
  - All technical requirements already implemented



Babrowski, S.; Heinrichs, H.; Jochem, P.; Fichtner, W. (2014): Load shift potential of electric vehicles in Europe: chances and limits, Journal of Power Sources 255, 283-293, doi: 10.1016/j.jpowsour.2014.01.019

Impact on the energy system: Central power plants (Germany, 12% market share, 2030)

- Instantaneous (controlled) charging has little impact on the electricity generation by conventional power plants and leads to (no) higher commissioning of new capacity.

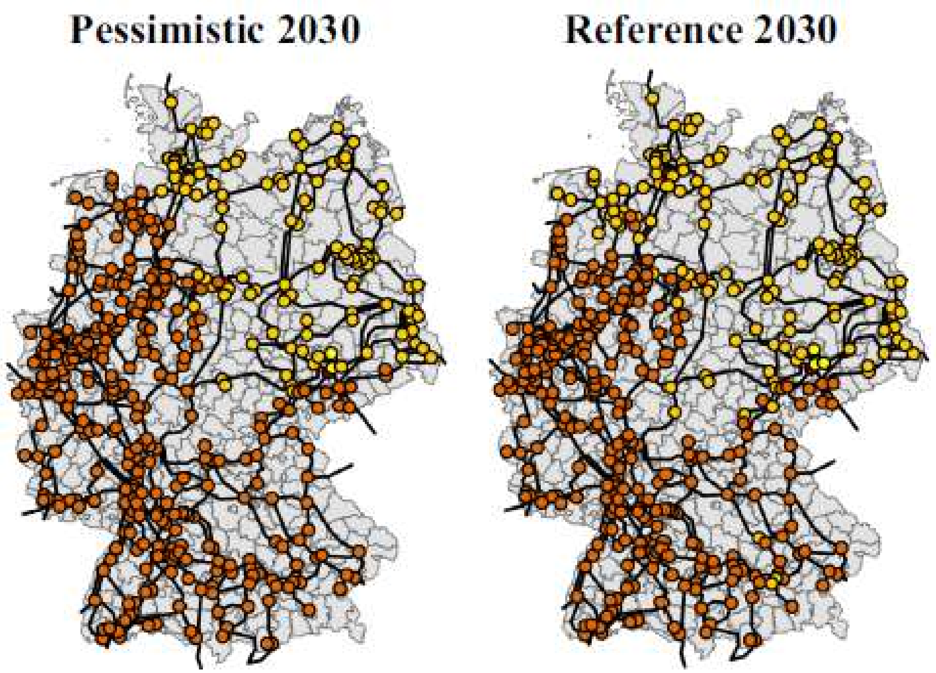


Jochem, P.; Babrowski, S.; Fichtner, W. (2015): Assessing CO2 Emissions of Electric Vehicles in Germany in 2030, Transportation Research A: Policy and Practice 78, 68-83, doi: 10.1016/j.tra.2015.05.007.

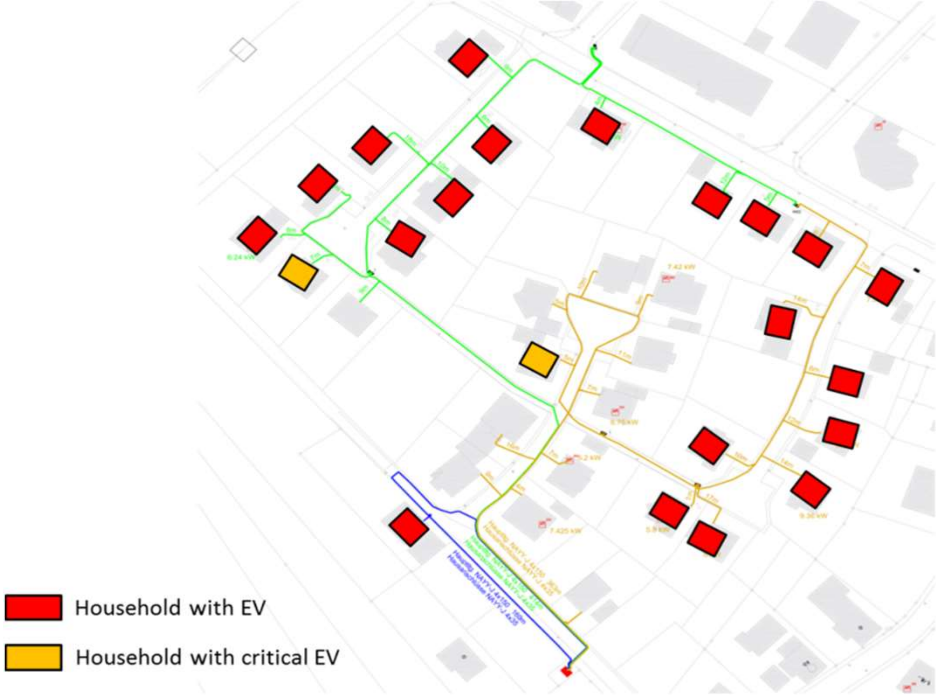
Impact on different power grid levels (GER, 2030)

- There is hardly any effect on the transport grid level
- The distribution grid is more vulnerable (depending on grid structure, current load, charging rate of EV, scheduling of charging, etc.)

Impact on the German transport grid in 2030



Impact on an example distribution grid



Heinrichs, H.; Jochem, P. (accepted), Long-term impacts of battery electric vehicles on the German electricity system, European Physical Journal Special Topics
EVREST (2014), Deliverable 4.1, project report, www.evrest-project .org

Greenhouse gases from additional electricity demand

- Measuring the emissions:
  - Annual average mix (1)

$$\frac{\sum_{t\in T} CO2_t^{\Sigma}}{\sum_{t\in T} E_t^{\Sigma}} \cdot \gamma \quad (1)$$

E: electricity demand; CO2: CO_2 emissions; γ: vehicle efficiency
Σ: Total E; EV: EV; $t\in T$: Time horizon

Country [2010]	Average CO_2 emissions in	
	kg CO_2/kWh_{el}	g CO_2/km
Austria	0.19	38
Belgium	0.22	44
Denmark	0.36	72
Finland	0.23	46
France	0.08	16
Germany	0.46	92
Greece	0.72	144[a]
Ireland	0.46	92
Italy	0.41	82
Netherlands	0.42	84
Poland	0.78	156[a]
Portugal	0.26	52
Spain	0.24	48
Sweden	0.03	6
UK	0.46	92
EU-27	0.43	86

Jochem, P.; Babrowski, S.; Fichtner, W. (2015): Assessing CO2 Emissions of Electric Vehicles in Germany in 2030, Transportation Research A: Policy and Practice 78, 68-83, doi: 10.1016/j.tra.2015.05.007

Greenhouse gases from additional electricity demand

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- Measuring the emissions:
  - Annual average mix (1)
  - Weighted average annual mix (2)

$$\frac{\sum_{t\in T}\left(\frac{E_t^{EV}}{E_t^{\Sigma}}\cdot CO2_t^{\Sigma}\right)}{\sum_{t\in T}E_t^{EV}}\cdot\gamma \quad (2)$$

E: electricity demand; CO2: CO_2 emissions; γ: vehicle efficiency
Σ: Total E; EV: EV; $t\in T$: Time horizon

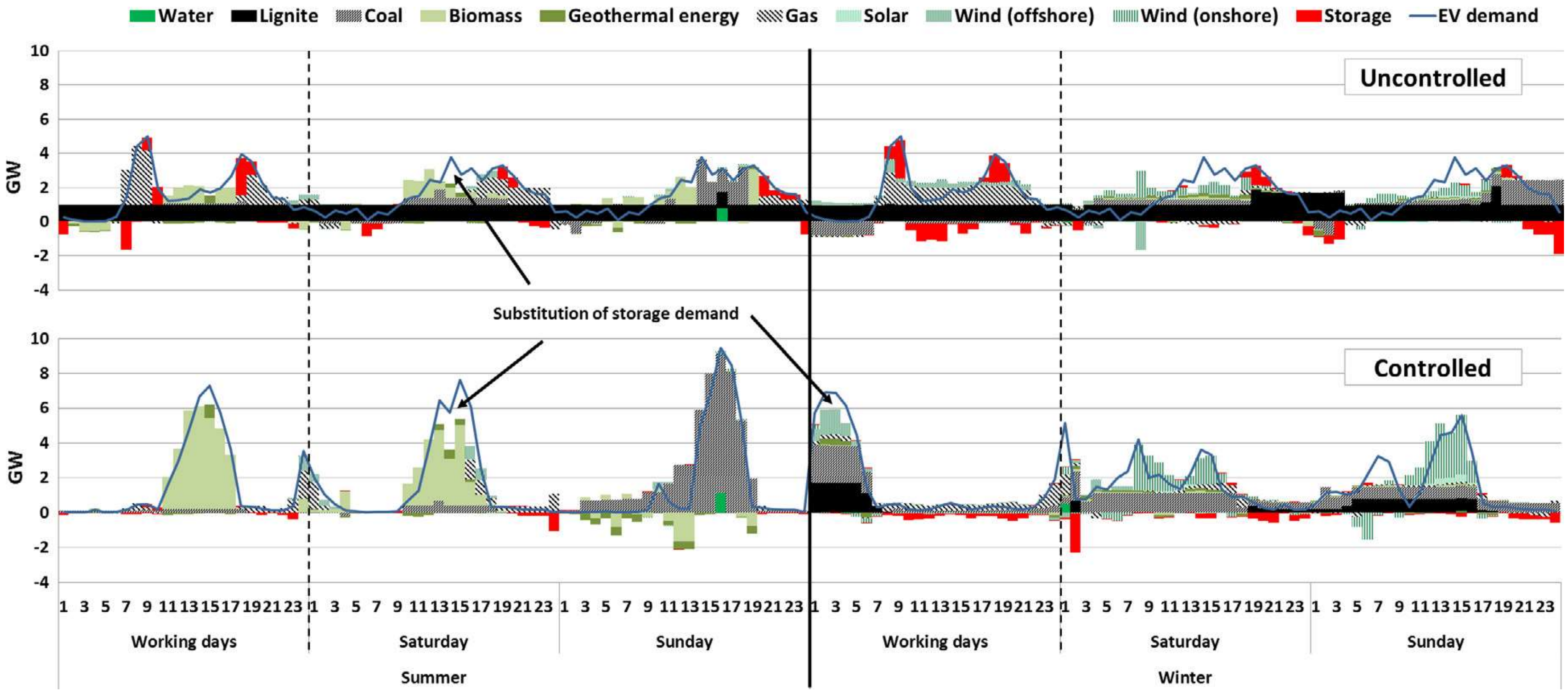
Jochem, P.; Babrowski, S.; Fichtner, W. (2015): Assessing CO2 Emissions of Electric Vehicles in Germany in 2030, Transportation Research A: Policy and Practice 78, 68-83, doi: 10.1016/j.tra.2015.05.007

Greenhouse gases from additional electricity demand

- Measuring the emissions:
  - Annual average mix (1)
  - Weighted average annual mix (2)
  - Marginal mix (3)

$$\sum_{t \in T} CO2_t^{EV} \cdot \gamma \qquad (3)$$

E: electricity demand; CO2: CO_2 emissions; γ: vehicle efficiency
Σ: Total E; EV: EV; $t \in T$: Time horizon



Jochem, P.; Babrowski, S.; Fichtner, W. (2015): Assessing CO2 Emissions of Electric Vehicles in Germany in 2030, Transportation Research A: Policy and Practice 78, 68-83, doi: 10.1016/j.tra.2015.05.007

Greenhouse gases from additional electricity demand

- Measuring the emissions:
  - Annual average mix (1)
  - Weighted average annual mix (2)
  - Marginal mix (3)
  - “Policy mix” (balancing emissions e.g. EU-ETS)

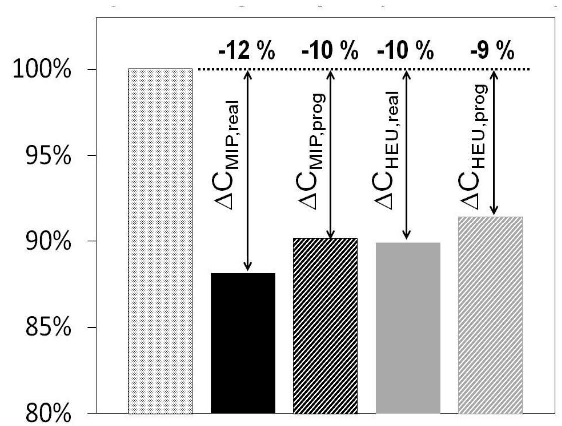
	Instantaneous charging		Controlled charging	
Germany, 2030, 12%	kg CO_2 / kWh_{el}	g CO_2 / km	kg CO_2 / kWh_{el}	g CO_2 / km
Annual average mix	0.29	58	0.29	58
Weighted average mix	0.29	58	0.25	50
Marginal mix	0.55	110	0.38	76
Policy mix	0	0	0	0

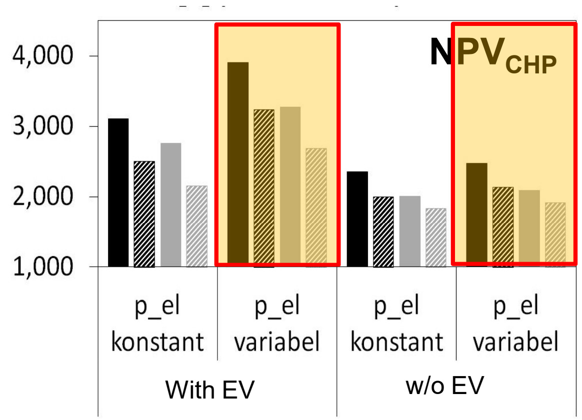
→ Policy makers should force the system to recharge EV only by carbon free electricity!

Jochem, P.; Babrowski, S.; Fichtner, W. (2015): Assessing CO2 Emissions of Electric Vehicles in Germany in 2030, Transportation Research A: Policy and Practice 78, 68-83, doi: 10.1016/j.tra.2015.05.007

Synergies with electricity from “renewables” and other decentralized energy technologies

- Due to the high load shift potential there are several **synergies with decentralised electricity generation technologies** such as photovoltaics (PV), combined heat and power (CHP) units, wind, etc. in a **smart grid** environment.





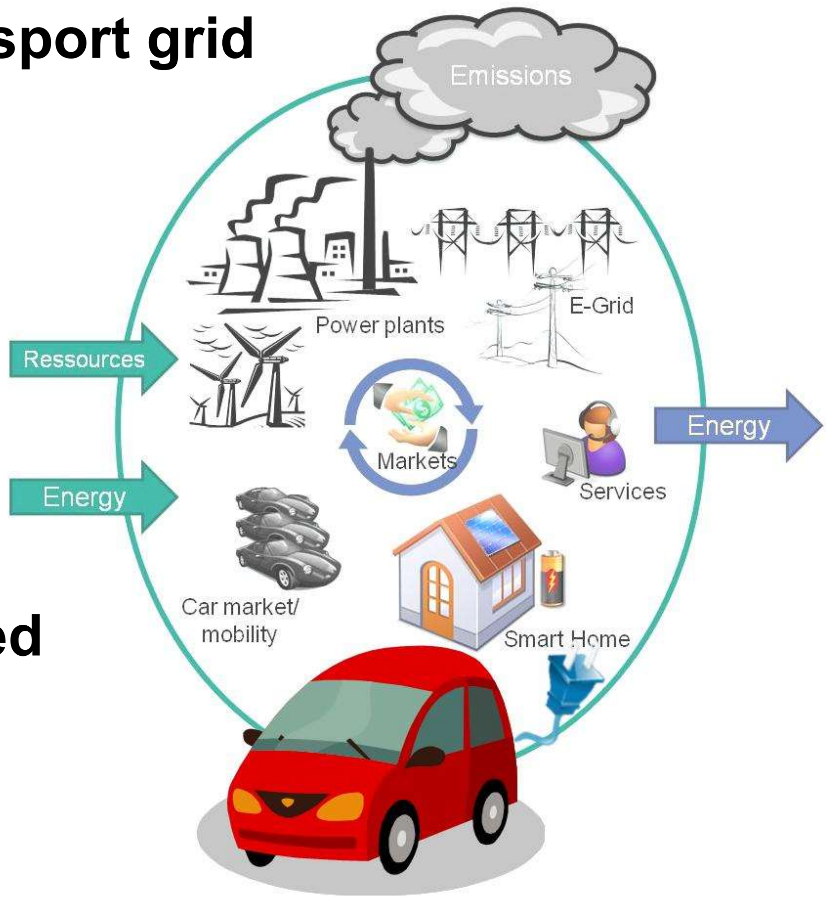
	NPV in average	share of analyzed homes with positive NPV for		
	BS	*PV*	*BS*	*PV&BS*
V2H	-24 €	98 %	50 %	100 %
EVopt	549 €	98 %	94 %	100 %
EVstart	1,042 €	68 %	100 %	90 %
EVno	862 €	42 %	100 %	64 %

Jochem, P.; Schönfelder, M.; Fichtner, W. (2015): An efficient two-stage algorithm for decentralized scheduling of micro-CHP units, European Journal of Operational Research 245, 862-874, doi: 10.1016/j.ejor.2015.04.016.

Kaschub, T.; Jochem, P.; Fichtner, W. (2013): Interdependencies of Home Energy Storage between Electric Vehicle and Stationary Battery, World Electric Vehicle Journal 6(4), 1144-1150.

Conclusions and outlook

- Controlled charging has a positive impact on the current **power plant** fleet (more full-load hours)
- There is only marginal impact on the **transport grid**
- The impact on **distribution grid** depends on several factors (grid architecture, conventional load, charging rate, etc.)
- **GHG emissions** from EV are for many countries already very advantageous.
  In other countries **policy measures** have a high potential
- EV have high synergies with **decentralised** (renewable) electricity generation
- EV support the **decarbonisation** of the energy system
- In **developing countries** these synergies are still limited



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